The Application of High Velocity Air Fuel Process for the Deposition Coatings

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Most commonly used methods of anticorrosion protection of large metal structures are painting and metal spraying. Painting is considerably cheaper than metal spraying, but the latter gives structures protection for up to 20 years and reduces maintenance costs substantially.

This paper presents a development of the thermal spraying system built on the principles of the high velocity air flame (HVAF) process. The designed thermal gun used for thermal spraying of Zn-Al wire, which is molten in the combustion zone and accelerated by a supersonic flow in the converging-diverging nozzle. HVAF sprayed coatings showed considerably higher bond strength than coatings obtained by the conventional methods, indicating the advantage of this method in areas where the adhesion strength is critically important. The highly dense structure of the coating obtained with HVAF eliminates a need for a top sealer coat, which is typically applied on sprayed coatings to extend service life. In addition, the developed thermal spray system provides competitive spray rates, high deposition efficiency, and the process can be easily performed on-site. Lower operating costs of the HVAF process in comparison with other high velocity systems makes this technology viable for thermal spraying applications for anticorrosion protection.

1. Introduction

With the rapid development of modern industry, quality of surfaces of structures, products and components are important from many aspects such as efficiency, reliability, maintenance costs and economy. A local failure on the surface usually causes the entire component to be rejected or it may lead to a failure of a machine or structure. It is estimated that in the developed countries, the loss caused by corrosion is up to 2-4 % of gross national product, reported by Hangong and Xi'an[1]. Thus, many countries have taken great efforts to improve the surface performance of parts in order to enhance the reliability of mechanical equipment parts and prolonging their service life.

In South Africa, having many industrial sectors of the economy positioned in the coastal regions and the large scale of the mining industry, there is a need for efficient and cost-effective surface protection technologies, especially for anticorrosion protection. Thermal spraying is an important surface engineering technology, which has a significant impact not only on improving

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surface properties of components and reducing material costs, but it could also be a substitute for environmentally unfriendly processes such as hard chrome plating. Thermal spraying has a 100-year history with some metal spraying processes invented at the beginning of the previous century. Since then, a number of thermal spray methods have evolved for anticorrosion protection, which are currently applied in industry. In this paper, a new surface protection technology for thermal spraying of anticorrosion metals is presented.

2. Overview of Thermal Spray Technologies for Anticorrosion Protection

The most economical way of protecting a base material against corrosion is by applying a coating layer of material, which is resistant to corrosion. Coatings must be able to withstand not only specific environmental conditions but also to exhibit certain mechanical properties. For these reasons, widely used corrosion resistant materials include metals, such as zinc, aluminium or their alloys, of which Zn/85 Al/15 is the most common. This alloy gives better performance than just zinc or aluminium coatings. Hot dip galvanization as a coating process has a number of limitations, which make it unsuitable in many applications including limiting coating thickness, large product size and no possibility of application on-site where structures are assembled to coat joints and fasteners. In addition, galvanized coatings include iron, which is an impurity, which reduces coating performance.

At the beginning of the last century, metallization or thermal spraying was invented as a technique specifically for anticorrosion protection by applying zinc coatings. In this process, the coating material is molten by a heat source and sprayed onto the substrate using the kinetic energy of the flow to achieve adhesion bonding between the coating material and the substrate surface. Since then, many technologies and processes of thermal spraying have been developed not only for surface protection against corrosion, but for thermal barrier coatings, wear resistance and electrical conductivity.

The first thermal spray process was developed by M.U. Schoop and H. Guenther in 1910[2]. The flame spray method uses the chemical energy of combustion of gaseous fuel and oxygen to generate heat to melt coating materials that can be in the form of powder, wires or rods. They are fed into the flame, melted, and sprayed by the expanding gas flow onto the substrate. Wires are widely used as the feedstock material, and the process is referred to as the wire flame process (figure 1). The advantages of the wire flame process include a basic system design and operation, low costs and versatility. The process limitation is the speed with which the wire can be melted in a flame without compromising coating quality. High feed rates cause some semi-molten material to be sprayed and as a result rough coatings are obtained.

A twin wire system, referred to as twin-wire arc, uses a direct-current electric arc, struck between two consumable electrode

wires, to achieve direct melting of the material. A compressed air jet, located behind the wire tips, sprays the molten material that continuously forms as the wires are fed into the arc (figure 2). The atomizing air is also used to accelerate the particles towards the substrate surface. The main advantage of this method, unlike the other techniques of thermal spraying, is that it minimizes the substrate heating and allows spray coatings onto polymers, fiberglass, wood, glass or paper products. Also, the twin-wire arc process provides the highest spray rate of all thermal coating processes, particularly of Zn-Al wires.

Wire flame and twin-wire arc techniques are classified as low velocity processes since the carrier gas or air has a low velocity and as a result low particle velocities are obtained in comparison with other spray techniques. It is generally accepted that the main drawbacks of these processes are high porosity and low bond strength, due to the low kinetic energy of the particles. For example, the coating bond strength of the Zn/85-Al/15 alloy obtained with the twin-wire arc process usually does not exceed 9 MPa, as reported by Varacalle *et al.*[3].

Generally, in order to obtain dense coatings with a high bond strength, a high velocity spray process is required, i.e. the higher the particle velocities, the better the coating quality. Recently a number of high velocity processes were applied for anticorrosion protection. These include HVOF, hybrid HVOF-arc and cold spray. The HVOF process introduced in the 1960s, is based on combustion of fuel with oxygen in a combustion chamber and expansion of gases in a De Laval nozzle producing supersonic gas flow, which is used to propel particles injected into the flow, as reported by Pawlowski[2]. Although HVOF can be used for spraying of Zn-Al alloys, it does not lend itself for applications on-site where anticorrosion coatings are typically required. In addition, the HVOF process generates temperatures far above the melting temperatures of zinc and aluminium, which can cause excessive oxidation of sprayed materials when entering the free stream. In some instances, shroud gas (nitrogen or helium) is used to shield the spray stream, but this complicates the overall system. Zha *et al.*[4] reported on the low temperature high velocity oxy fuel (LTHVOF) system, where the combustion temperature is reduced by injecting nitrogen into the gun chamber. The LTHVOF gun was reportedly used for thermal spraying of materials with low melting points, such as copper. The drawback of this method is that it is used only for powders, which usually provide lower spraying rates in comparison with thermal spraying of wires.

A hybrid HVOF-arc system, which was recently reported in literature by Kosikowski *et al.*[5], is a combination of the twin-wire arc and HVOF processes where consumable wires are molten by electric arc and then accelerated by a high velocity jet generated with HVOF instead of the compressed air. However, hybrid HVOF-arc systems can only operate in a workshop environment, whereas the majority of applications are on-site, which limits this method's capabilities.

Cold gas dynamic spraying technology or cold spray was developed in the mid-1980s at the Institute of Theoretical and Applied Mechanics of the Russian Academy of Science in Novosibirsk by Dr Anatolii Papyrin and colleagues[6]. In the cold spray process, compressed gas accelerates small (1-50 µm) particles to a high velocity (300-1200 m/s). In cold spray, compressed gas (1.5-3.5 MPa), usually nitrogen, is divided into two streams (figure 3). One is heated to 373-873 K by electric heater and directed into the chamber and accelerated by the De Laval nozzle to supersonic velocity. The other stream of compressed gas is used to convey the powder from a powder feeder into the chamber before the convergent
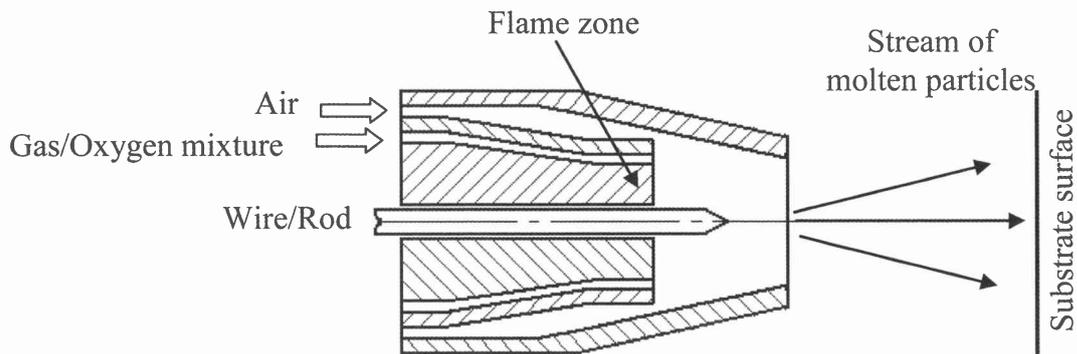

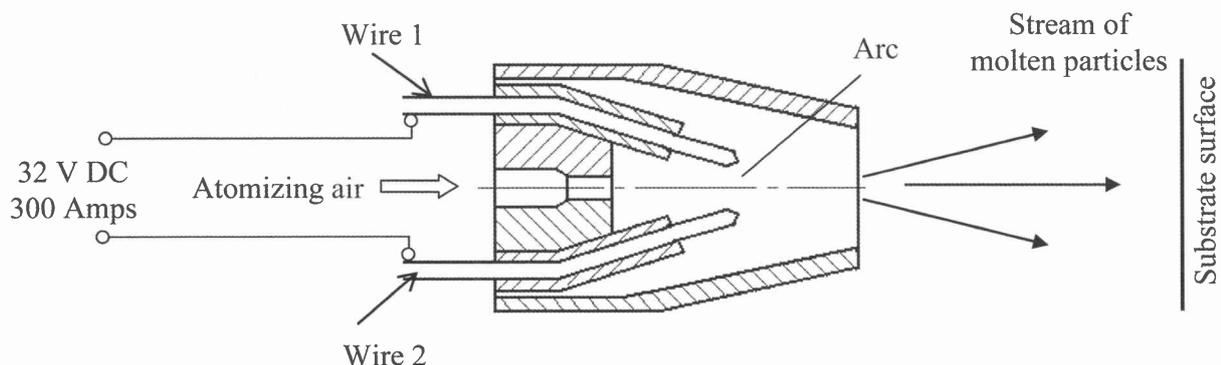Figure 1: Diagram of wire flame spraying

Figure 2: Diagram of twin-wire arc spraying

section of the nozzle. The particles are heated to a temperature, which is lower than the melting point of the spray material, so oxidation is minimised. In order to produce a high performance coating, particle velocity must exceed a critical value, which is 500-900 m/s depending on particle size. Otherwise, particles rebound from the substrate. However, the results reported by Blose and Vasquez[7] show that cold spray is not suitable for spraying Zn-Al alloys due to high costs and the difficulty of building a portable system. The detonation gun or D-gun™ is another high velocity technique. The D-gun™ was developed in the 1980s for spraying at high velocities using the energy of detonation waves. Generally, highly dense coatings are obtained with the D-gun™. However, this method is only suitable for spraying of powders therefore limiting the spray rate and making this method not economically viable for anticorrosion protection.

All the abovementioned high velocity technologies are not suitable for spraying of Zn-Al mainly due to economic reasons

same time. Correct air passages inside the thermal gun, and their dimensions, are critical for HVAF system performance.

The HVAF process is governed by the thermodynamic cycle derived from an air-standard Brayton cycle, i.e. combustion at constant pressure, expansion in a nozzle and heat rejection. A compression stage is not included since compressed air is supplied to the thermal gun from an external source, e.g. a diesel or electric compressor, therefore no flow energy is used for driving a compressor. Combustion of fuel, mostly liquid fuels, takes place inside the combustion chamber after which gases expand in the De Laval nozzle. Using the standard analysis for compressible flows and the basic assumptions for an ideal gas, the geometry of the combustion chamber and the exit nozzle are derived to obtain the required gas flow parameters with the aims to:
❑ achieve stable and complete combustion;
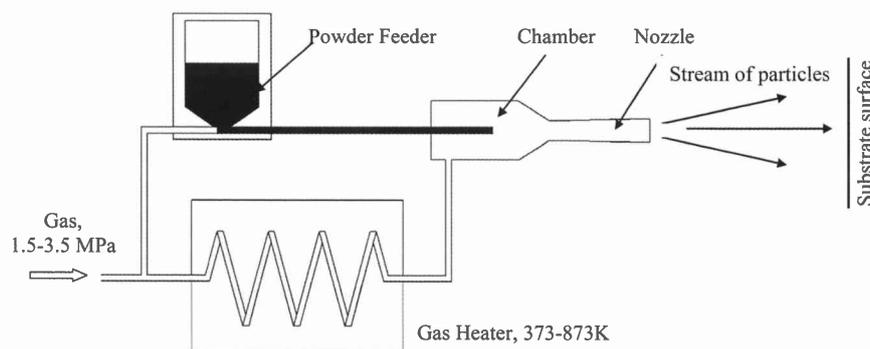❑ generate temperatures sufficient for melting of sprayed materials;

Figure 3: Schematic of cold gas dynamic spraying

or inability to spray on-site. HVAF, on the other hand, is considerably less expensive because it is based on combustion of fuel and compressed air, and it can be easily used on-site. HVAF was developed before HVOF, with some references dating in the 1960s. Turn[8] reported that HVAF was initially applied for cutting rocks by thermal spallation, then for cleaning of runways, cutting concrete and later, for thermo-abrasive.

3. HVAF versus HVOF

HVOF produces higher flow velocity than HVAF. However, the flame temperature is also much higher in HVOF, which causes oxidation of spray material. HVOF and HVAF are similar in the sense that both methods employ a combustion process of fuel under pressure to obtain high velocity flows, but their designs are significantly different. The combustion chamber of a HVOF system is a water cooled burner, where fuel (liquid or gaseous) and oxygen are injected axially, mixed, and burned producing combustion gases, which are then accelerated in the converging-diverging nozzle (figure 4a). A HVAF combustion chamber is designed on the principles of a jet engine combustor working on liquid fuel and compressed air, which is supplied to the combustion zone in two stages; primary air for combustion and secondary air for cooling of the flame, because the stoichiometric temperature of the air/paraffin mixture is too high for the combustion chamber housings and the nozzle (figure 4b). Hence, the design of a HVAF thermal gun is more complex since the compressed air fed into the thermal gun should provide stable, efficient combustion, and cooling of the thermal gun parts at the

❑ obtain the highest gas flow exit velocity at a flow rate sufficient to propel coating materials.

High velocity oxy and air flame systems use mainly paraffin as a liquid fuel, usually Jet A-1 type. The empirical formula of paraffin is C_nH_{2n+2}, where n is the number of carbon atoms. According to Warnatz *et al.*[9], the chemistry of combustion and specifically ignition of paraffin or diesel is quite complex and is described according to some sources by 39 elementary chemical reactions and 28 species. The stoichiometric mixture of paraffin and oxygen has an adiabatic flame temperature of 3300 K and a heat of combustion of 37 MJ/ℓ of paraffin. A typical HVOF system operates at 12 ℓ/h of fuel and 56 m³/h of oxygen at 1.43 MPa, producing approximately 125 kW of power of which 40 % is heat that needs to be dissipated[10]. Therefore, a sufficient water cooling system for HVOF is critically important and it contributes substantially to the operating costs.

The adiabatic flame temperature for the stoichiometric mixture of paraffin and air is approximately 2300 K. However, the combustion process of HVAF, similarly to the combustors of jet engines, runs at a significantly higher air/fuel mixture than the stoichiometric value. The flame is diluted by the air before entering the nozzle in order to avoid overheating of air-cooled components, and the maximum flame temperature inside the thermal gun is estimated as 2000 K[11]. The HVAF thermal gun used in this research consumes 8 ℓ/h of paraffin using 180 m³/h of compressed air at 0.55 MPa pressure, generating 80 kW of power without water cooling and therefore having higher efficiency and lower costs than HVOF.
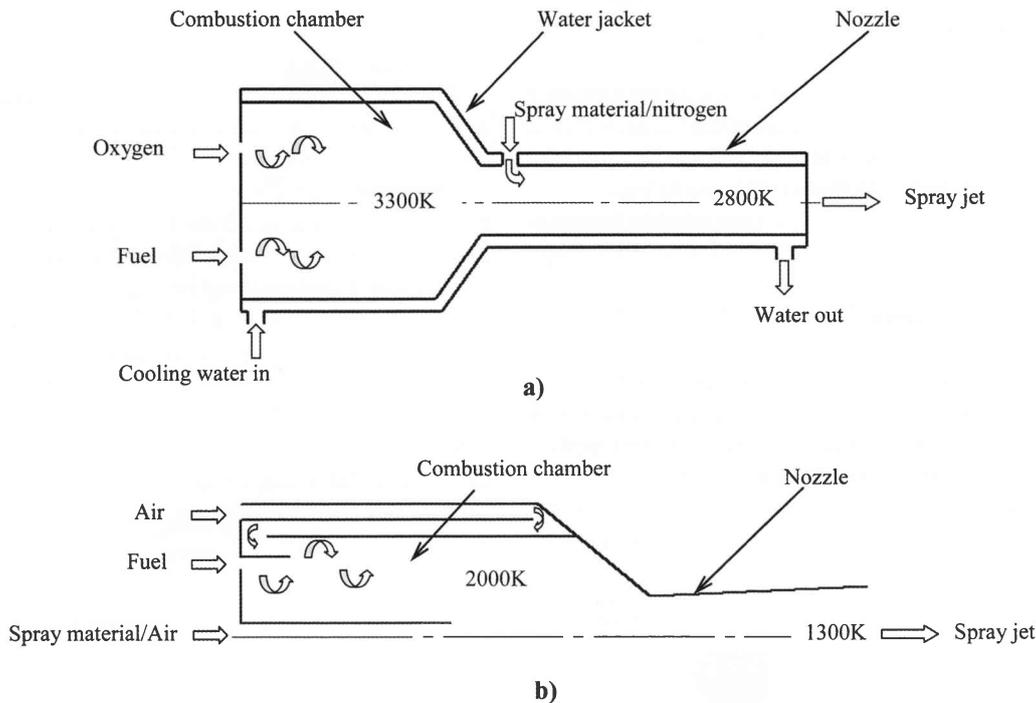
Figure 4: Schematics of: a) HVOF burner, b) HVAF thermal gun (half cross-section)

4. Design of the HVAF Thermal Spraying System

4.1 Thermal gun design

The design of a thermal spraying system depends on the type of feedstock material, feeding mechanism and the thermal gun design. Zn-Al alloys can be sprayed as powders or wires depending on equipment used. Powders can be injected into the thermal gun in two ways, axially through the combustion chamber or radially in the nozzle. In the experiments, the Zn-Al powder was injected axially into the high temperature zone and a substantial evaporation was noticeable. This is attributed to the small size of powder particles and the low melting temperature of Zn-Al, which is in the order of 370 K. By injecting powders radially at the exit of the nozzle, where the gas temperature is considerably lower (1300 K), lower evaporation rates could be achieved. However, spraying rates would be low as the amount of powder that can be injected across the flame is limited. Wire, on the other hand, can be melted in the combustion zone of a thermal gun in a more controlled manner and fed at high rates.

The main challenge in designing a HVAF system for spraying of Zn-Al alloys was to achieve an effective combustion process for melting the fed wire in such a way that it would provide on efficient spraying process with minimum losses due to evaporation. The parameters which determine the efficiency of the thermal spray process of Zn-Al wire include the combustion process parameters, the wire entry position into the combustion zone, the wire feeding rate, and the nozzle geometry. Coating quality and the productivity of the spraying process among other are determined by empirical parameters, such as spraying distance, spray pattern, the linear speed of the gun, and coating thickness of a single pass.

The developed thermal spraying system consists of the HVAF thermal gun, the wire feeder and the controller. The thermal spraying gun is based on a design, which was previously developed for the thermo-abrasive blasting process[12], modified for the thermal spraying process. The main features of the thermal gun include the atomizer, the combustion chamber, the wire guide and the nozzle (figure 5). A high velocity flow is achieved by expansion in the De Laval nozzle of high enthalpy gas obtained in the combustion process of burning liquid fuel and air inside the combustion chamber under pressure. After the ignition of the air/fuel mixture with an electric arc or pilot flame (not shown), combustion is self-sustained. The compressed air supplied to the zone is directed through the annular passages between the housings, removing heat from the nozzle and the housings. The dilution holes in the combustion chamber housing cool the flame entering the nozzle. Hence, the dilution holes diameters increase along the housing towards the nozzle in order to inject more air. The air/fuel mixture ratio of 30:1 was determined experimentally based on the highest feed rate of Zn-Al wire that can be melted and sprayed on a substrate to achieve a smooth surface texture, providing the highest deposition rate. The air/fuel ratio also needs to be limited in accordance with the temperature that the air cooled chamber housing and the nozzle can be subjected to for a prolonged period of time.

For the thermal spraying process, the following parameters are important: wire diameter, wire feed rate, and entering position inside the combustion zone. Generally, the coating wire diameter that can be utilized by a system is determined by heat generated through combustion per unit time, the gas flow rate and the nozzle throat diameter. Since the thermal gun geometry parameters were fixed, a wire size of 2 mm diameter, as the most common size, was used in the experiments, although larger diameter can also be sprayed.

Zn-Al wire is fed by an electric wire feeder through the rear of the combustion chamber employing a wire "push" type principle, which is efficient up to a 5 m distance between the wire feeder and the thermal gun, established experimentally. If a longer distance is required, a "pull" type principle for wire feeding can be employed by means of adding a wire driving
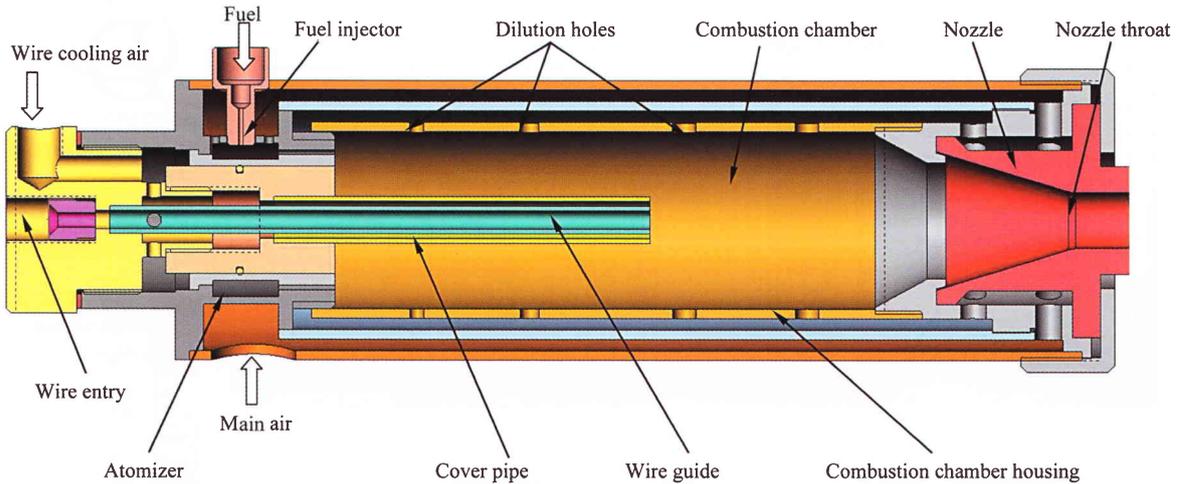
Figure 5: CAD model of the thermal spraying gun

mechanism attached to the thermal gun similar to that used in wire flame systems.

The position of wire entry into the combustion zone influences a number of spraying parameters and ultimately the spraying rate (figure 5). In the case of a longer distance from the nozzle throat, melted material was noticeable on the walls of the combustion chamber indicating an early melting process, which may also result in excessive material evaporation and losses of the sprayed material. A shorter distance between the wire entry and the nozzle throat, on the other hand, delays melting of the coating material, slows wire feeding and results in lower spraying rates. In experiments, the optimum distance from the exit of the wire guide to the nozzle throat was determined as 70 mm. In order to prevent melting of the coating wire inside the wire guide due to the high combustion temperature, which would result in blocking of the passage, an additional protection pipe is used to create an annular passage for cooling air. As shown in figure 5, compressed air is supplied into the wire guide and the cover pipe to provide cooling and prevent melting of the coating wire before entering the combustion zone.

The maximum speed of wire feeding was assessed on the basis of coating quality (surface roughness) and the highest deposition efficiency. The wire feed rate was determined experimentally as 5 m/min. Higher wire feed rates typically result in a rougher surface finish (above R_z =80 μm) with some partially melted pieces of material. Rougher coating surfaces would require more sealer, which is typically applied as a final coat on top of the metal coating to close possible pores and prolong service life. A lower wire feed rate is generally preferred as it provides a smoother coating surface. However, it might cause significant material evaporation and a lower deposition efficiency, which was measured according to ISO 17836.

Another challenge in using a HVAF system for thermal spraying of Zn-Al wire is to eliminate clogging of the nozzle with molten material. In traditional wire flame and twin-wire arc processes, wire is melted and sprayed directly without a nozzle as shown in figures 1 and 2, while in the HVAF thermal gun, wire is melted inside the thermal gun before entering the nozzle. The correct nozzle geometry, therefore, is not only important for achieving the highest multiphase flow velocity, but should also prevent adhesion of molten material to the nozzle inner walls.

The calculations of the transition curve for the inner contour in the divergent section of the De Laval nozzle are done by the method developed by Prandtl and Busemann[13] in 1929. For a given throat-exit area ratio of the nozzle inner contour and using the ideal gas properties, the Mach number M at the nozzle exit and, therefore, the temperature and pressure ratios can be calculated using equation 1. By iterating the throat-exit area ratio, a perfectly expended flow can be obtained, i.e. when the exit gas pressure is equal to the atmospheric air pressure.

$$\frac{A}{A^*} = \frac{1}{M}\left[\left(\frac{2}{\gamma+1}\right)\left(1+\frac{\gamma-1}{2}M^2\right)\right]^{\frac{(\gamma+1)}{2(\gamma-1)}} \qquad (1)$$

where

A^* = the critical area when $M = 1$ at stagnation conditions,
A = the nozzle area at a given section along the nozzle axis,
γ = the ratio of the specific heat at constant pressure to the specific heat at constant volume.

The thermal gun nozzle geometry parameters for *a perfectly expended flow* are shown in table 1[14]. However, thermal spray nozzles are typically made with a straight bore instead of diverging shape for manufacturing reasons, and are 100-150 mm long in order to transfer more momentum to particles. Figure 6 shows the flow velocity distribution in a 100 mm nozzle of a thermal gun modelled with CFD showing underexpended flow since the flow starts to decelerate in the nozzle. The diagram of the particle's track and velocity in the nozzle (figure 7) shows that the gas flow accelerates particles mainly in the first half of the nozzle, from 50 m/s to 170 m/s, because the highest acceleration of the gas flow occurs in this region. When the gas velocity starts to decrease due to shock waves in the second half of the nozzle and in the free stream, particles gain very little velocity, from 170 m/s to 187 m/s. This indicates that shorter nozzles can be effectively used for thermal spraying. Longer nozzles would be justified when the spraying material requires higher

Throat diameter (mm)	Length of diverging section (mm)	Area ration A_{exit}/A_{throat}	Temperature ratio	Pressure ratio	Mach number
14	70	1.62	0.57	0.135	1.95

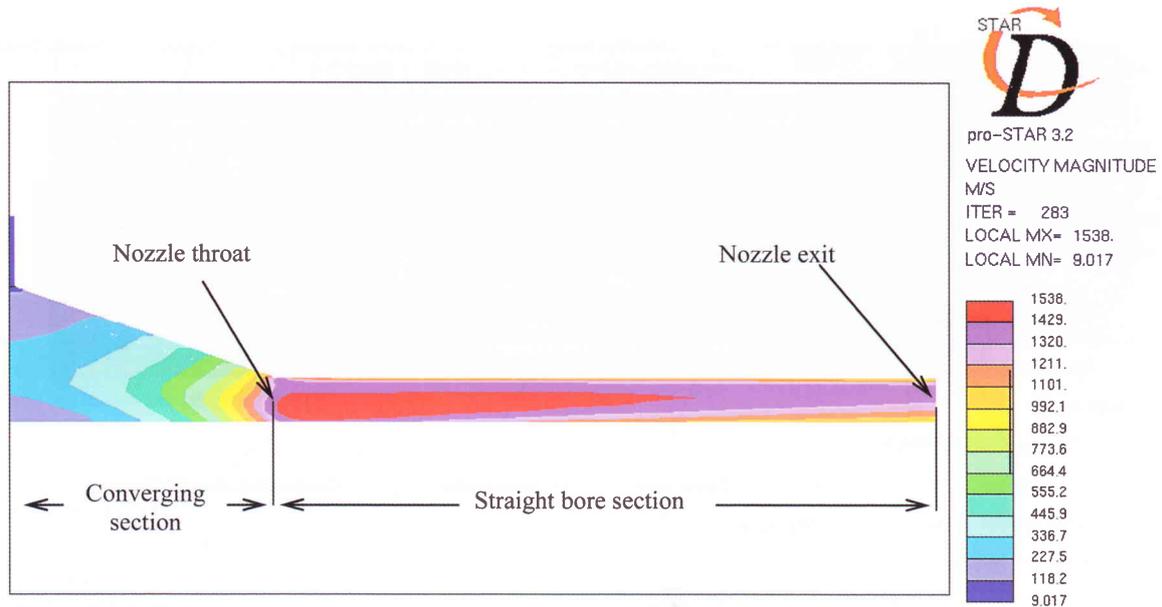Table 1: Parameters of the thermal gun nozzle a perfectly expended flow

Figure 6: CFD modelling of the gas flow velocity in the thermal gun nozzle (half section)

melting temperature or large particles in order to transfer more heat or momentum from the flow.

In the experiments with 100 mm long nozzles, the bore was soon clogged with the sprayed material, which was attributed to the lower temperatures of the nozzle inner wall closer to the nozzle exit and consequent solidification of molten particles. There were no signs of nozzle clogging in the converging and straight bore sections of the nozzle up to 20 mm downstream from the throat, which was chosen for the nozzle design length. In terms of the combustion gas parameters, this nozzle is less efficient because the supersonic flow is regarded as overexpanded. However, in this case it can be justified as it prevents nozzle clogging. The nozzle throat diameter of 14 mm was used which is the since the combustion chamber parameters have not changed.

4.2 Control system

Figure 8 shows a diagram of the complete HVAF thermal spraying system, which includes the thermal gun, the wire feeder, the fuel system and the controller. The fuel pump and the wire feeder operate on 220 V, whereas the rest of the system operates on 12 V DC to reduce the risk for the operator as some valves are fitted to the thermal gun.

The system starting procedure is as follows: at a push of the start button, the flame glow plug is heated up for 20 sec. Following that, valve V1 opens air, regulated by valve V3, while valve V2 opens fuel to the flame glow plug to ignite a flame. Once the pilot flame is obtained, the combustion process can be initiated by pressing the "deadman" handle, which triggers the supply of air and fuel into the combustion chamber by opening valves V4 and V5. After a short period of time when the combustion process is stabilized, wire feeding is started automatically together with wire cooling (valve V6). The "deadman" handle involves a spring return such that when released the handle automatically opens, switching off the supply of air and fuel to the gun.

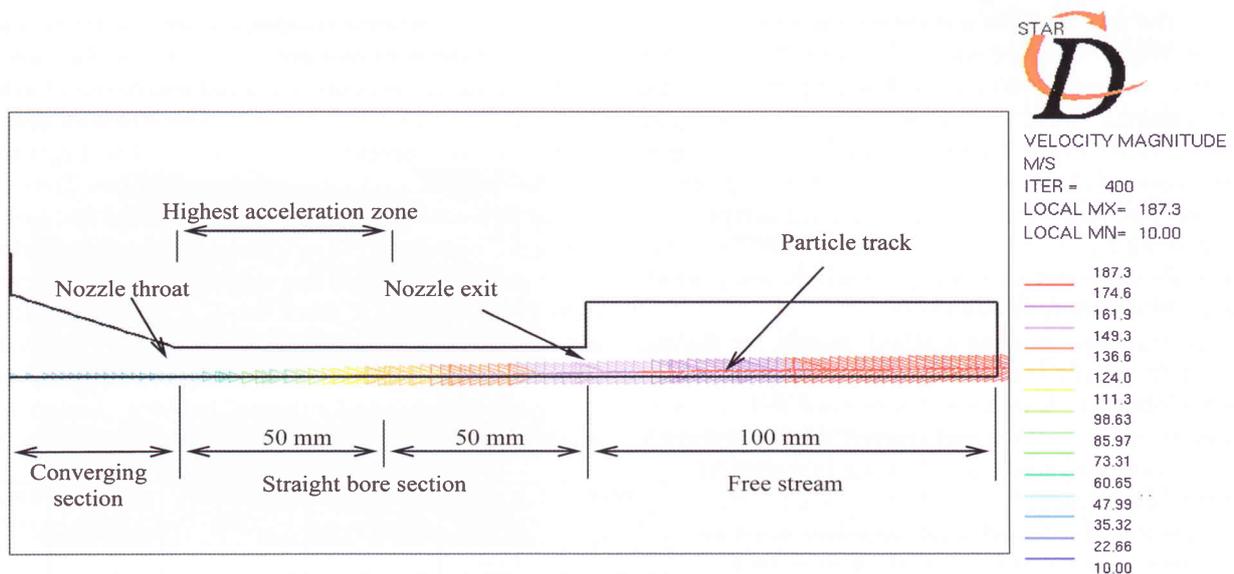The air/fuel mixture ratio can be adjusted by the operator with

Figure 7: CFD modelling of the solid particle trajectory and velocities in the flow inside the thermal gun nozzle and free stream
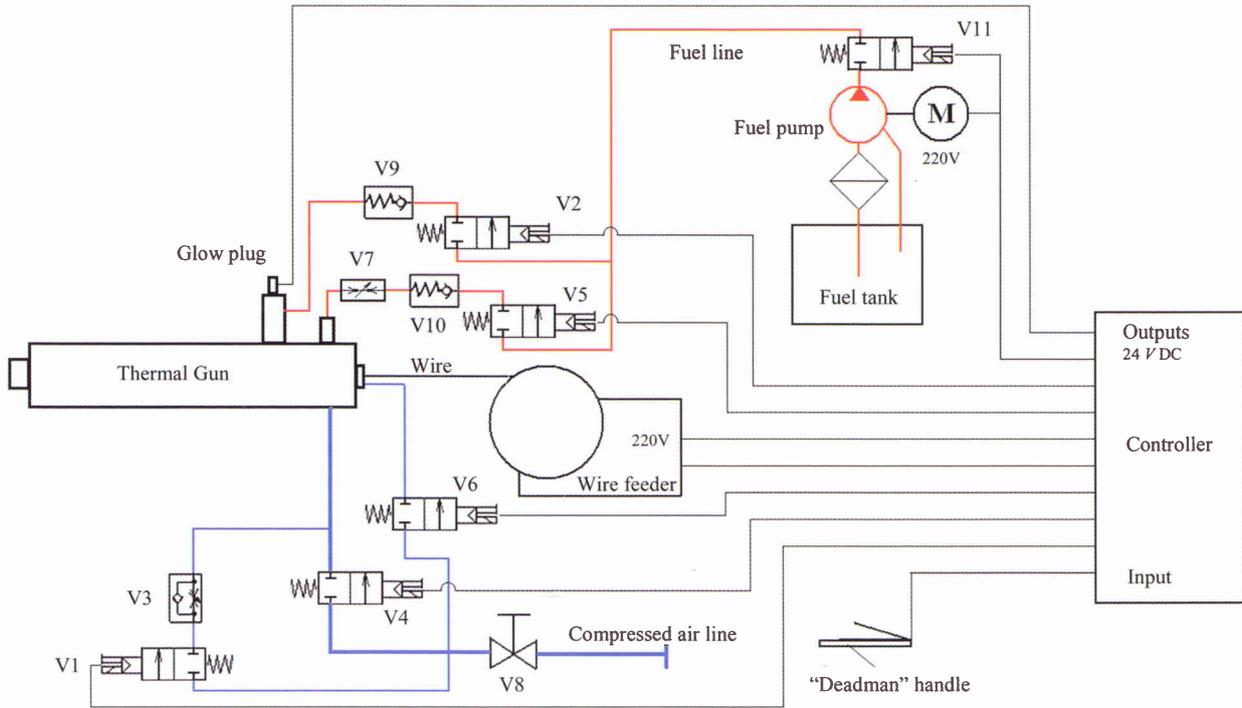
Figure 8: Diagram of the control system of the complete HVAF thermal spraying system

valves V7 and V8, which is necessary when a compressed air pressure fluctuates. Non-return valves V9 and V10 are used in the fuel lines for safety reasons. By releasing the "deadman" handle, the process is stopped, however, cooling of wire inside the thermal gun continues for 30 s to prevent wire melting in the hot combustion chamber.

For a machine manipulator of the thermal gun, such as an industrial robot, all the operating functions can be easily automated. Combustion can be monitored by a flame sensor, while the air/fuel mixture can be regulated by a basic feedback control function utilising data read from the flow meters and pressure transducers.

5. Results and Discussion

In experiments, a 2 mm diameter Zn/85-Al/15 TAFALOY 02A wire was sprayed on steel substrates with the HVAF thermal gun. The wire was fed through the combustion chamber of the thermal gun by a wire feeder operating at a 5 m/min feed rate. Prior to thermal spraying, the steel samples were prepared by grit blasting using mineral slag, but not preheated or degreased, in order to replicate the thermal spraying conditions of a real operating environment. The cylindrical low carbon steel samples were coated on their faces with a 150-200 µm thick layer for the adhesion test according to DIN EN 582. The low carbon steel plates were sprayed for determining the deposition rate according to ISO 17836.

The thermal spraying process was performed manually with consecutive vertical and horizontal passes. The spraying distance from the substrate surface was 300-350 mm leaving the temperature of the substrate relatively low, therefore substrate cooling was not necessary during or after thermal spraying. Table 2 includes the HVAF thermal gun parameters used during the thermal spraying process. The compressed air was obtained from a 35 kW diesel compressor. Aviation paraffin Jet A-1 was used as fuel.

The obtained thermal spray process parameters are presented in table 3. An average spray rate of 6 kg/h with 2 mm diameter was found optimal to produce coatings with smooth surface finish, which were compared with the samples sprayed with twin-wire arc. Although the spray rate is noticeably lower than 9.5 kg/h typically reported for twin-wire arc, it is believed that larger wire

Air flow rate (m³/min)	Air pressure (kPa)	Fuel flow rate (ℓ/min)	Fuel pressure (kPa)	Pressure in combustion chamber (kPa)
3.5	550	0.3	550	550

Table 2: Parameters of the HVAF thermal spraying gun

diameters, up to 4.76 mm, could be used to increase spray rates in HVAF as the gas temperature and the flow rate generated by the thermal gun is sufficient to spray more material.

With a single pass, a 80-100 µm thick coating is deposited with a 0.5 m/min traverse speed of the thermal gun and a spray pattern of approximately 50 mm. This indicates that a single thermal spray coat would be sufficient for most applications as the specification typically requires a 80 µm thick protective coating. Figure 9 shows the sample, a corroded steel pipe, which was first grit blasted (figure 9a), then sprayed with Zn/85-Al/15 (figure 9b) and finally painted with a coat of sealer (figure 9c) to achieve a duplex coating system for extra corrosion resistance. Typical matte surface finish of the Zn/85-Al/15 coating with

Spraying Parameter	Value
Wire diameter, (mm)	2
Wire feed rate, (m/min)	5
Traverse speed (m/s)	0.5
Thickness per pass (µm)	80-100
Spray rate (g/min)	100
Deposition efficiency (%)	70

Table 3: Parameters of thermal spraying of Zn-Al wire with HVAF

Figure 9: Picture of the sample: (a) grit blasted, (b) with Zn-Al coating (c) with sealer coating on top of Zn/85-Al/15 coating (duplex coating)

some inclusions of aluminium on the surface can be observed on the sample. Eight samples were subjected to the salt spray tests according to ISO 9227 and showed no signs of corrosion after 240 h of testing according to the results of the Institut für Korrosionsschutz, Dresden (figure 10).

Adhesive tensile strength of the Zn/85-Al/15 coatings was measured with a pull test (Instron 1185 mechanical testing machine) according to DIN EN 582 where the cylindrical specimen is coated on the face and glued to the face of another cylinder. By measuring the stress at which the coating fails, the adhesion tensile strength of the coating is determined. The measured bond strength of six carbon steel samples, grit blasted before thermal spraying, ranged from 13.8 MPa to 18.2 MPa, with an average of 16.5 MPa. This is almost twice as high as the bond strength reported for Zn-Al coatings deposited with Twin-Wire Arc, reported by Varacalle et al.[3].

6. Conclusion

In this paper, a new technology for anticorrosion protection is presented. The HVAF process can be efficiently used for thermal spraying of Zn/85-Al/15 wire to produce coatings of high quality at high spray rates. During HVAF thermal spraying, the substrate is not subjected to high temperatures because of the large spray distance, the high spray rate, large spray pattern and short dwell time. This is a definite advantage of this method indicating that substrates with low melting points, such as bronzes, plastics, plaster, and wood, can be coated. Parts made of such materials often require metallic protective coatings. For example, in metal faced mould making, patterns made of plaster or wood are sprayed with zinc and backed up

with epoxy. Up to now, metal faced mould making was only possible with twin-wire arc.

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Figure 10: Picture of the sample after 240 h of the salt spray test carried out by the Institut für Korrosionsschutz